EX PARTE OR LATE FILED

DOCKET FILE COPY ORIGINAL

ANN BAVENDER*
ANNE GOODWIN CRUMP*
VINCENT J. CURTIS, JR.
PAUL J. FELDMAN*
ERIC FISHMAN*
RICHARD HILDRETH
EDWARD W. HUMMERS, JR.
FRANK R. JAZZO
CHARLES H. KENNEDY*
KATHRYN A. KLEIMAN
BARRY LAMBERGMAN
PATRICIA A. MAHONEY
M. VERONICA PASTOR*
GEORGE PETRUTSAS
LEONARD R. RAISH
JAMES P. RILEY
MARVIN ROSENBERG
KATHLEEN VICTORY*
HOWARD M. WEISS

*NOT ADMITTED IN VIRGINIA

FLETCHER, HEALD & HILDRETH, P.L.C.

ATTORNEYS AT LAW

11th FLOOR, 1300 NORTH 17th STREET

ROSSLYN, VIRGINIA 22209

(703) 812-0400

TELECOPIER

(703) 812-0486

INTERNET

HILDRETH@ATTMAIL.COM

ROBERT L. HEALD
(1956-1983)
PAUL D.P. SPEARMAN
(1936-1962)
FRANK ROBERSON
(1936-1961)

RETIRED
RUSSELL ROWELL
EDWARD F. KENEHAN
FRANK U. FLETCHER

OF COUNSEL
EDWARD A. CAINE*

WRITER'S NUMBER
(703) 812-0403

RECEIVED

NOV 17 1994

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

November 17, 1994

Via Hand Delivery
Mr. William F. Caton
Acting Secretary
Federal Communications Commission
1919 M Street, N.W., Room 222
Washington, D.C. 20554

Re: Ex Parte Presentation -- ET Docket Nos. 94-32 and 94-124

Dear Mr. Caton:

You are hereby advised that on November 16, 1994 the attached written *ex parte* presentations were made in the above-referenced proceeding to the following Commission personnel:

- -David Siddall, Esq. (Office of Comm'n Ness)
- -Ruth Milkman, Esq. (Office of Chairman Hundt)
- -Jill Luckett, Esq. (Office of Comm'n Chong)
- -Mr. Lawrence Petak, Office of Engineering and Technology

The written presentations were delivered to the above personnel during meetings between such personnel and representatives of the Committee on Radio Frequencies ("CORF"), discussing the topics set forth in the written presentation. An original and one copy of this letter and two copies of each of the attached presentations are being filed. If additional copies of this filing are required, CORF will supply them immediately upon request.

Should any questions arise concerning this matter, or should any additional information be necessary or desired, please communicate with this office.

Very truly yours,

FLETCHER, HEALD & HILDRETH

Paul Feldman

Paul J. Feldman
Counsel for Committee on
Radio Frequencies

Enclosures

cc: David Siddall, Esq.; Ruth Milkman, Esq.; Jill Luckett, Esq;
Mr. Lawrence Petak - all w/o enc.

COMMITTEE ON RADIO FREQUENCIES
NOVEMBER 16, 1994 BRIEFING

- CORF is an arm of the National Research Council, which itself was established by the National Academy of Sciences.

- CORF represents the interests of the Earth Exploration-Satellite Service, the Space Research Service, the Radio Astronomy Service and other users of the radio spectrum engaged in scientific research.

- Radio astronomy is a vitally important tool used by scientists to study our universe. Furthermore, radio astronomy has produced substantial terrestrial benefits through the development of very-low-noise receivers, and other radio astronomy technologies have been used to e.g., measure fault motions, leading to the identification of potential earthquake zones. These benefits of radio astronomy, obtained through years of work and substantial federal investment, as well as future benefits, must be protected.

- As passive users of the spectrum, astronomers study natural sources of radiation throughout the electromagnetic spectrum. The emissions that radio astronomers review are extremely weak -- a typical radio telescope receives only about one-trillionth of a watt from even the strongest cosmic source. Radio astronomy is therefore particularly vulnerable to interference from licensed and unlicensed users in bands allocated to radio astronomy, and from spurious emissions from users of neighboring bands. Accordingly, if the benefits of radio astronomy are to be protected, wise spectrum management must be used.

- Big LEO The Low Earth Orbit Satellite negotiated rulemaking produced a very workable result, and CORF appreciates the efforts and work of Commission staff participants Tom Tycz and Harry Ng. This proceeding demonstrates that when the Radio Science community is allowed to participate as an equal, it can protect the needs and interests of passive users of spectrum, while making compromises that meet the needs of other users.

Reallocation of Spectrum Below 5 GHz

- CORF is pleased to see that the Commission has recognized the need, noted by NTIA, Cornell and CORF, to protect radio astronomy operations in licensing the 2390-2400 and 2402-2417 MHz bands. We will respond to Commission's questions in the NPRM in detail.
- Nature of MSS proposals in paras. 12 & 19?

Authorization of Services Above 40 GHz
- CORF has made a substantial study of the use of millimeter wave bands. We anticipate providing a detailed and generally supportive response to the NPRM.

Spread Spectrum
- It is important to restrict transmissions to the needed frequency range. New research results indicate that modulation techniques can effectively address this concern.

VIEWS OF THE COMMITTEE ON RADIO FREQUENCIES

CONCERNING FREQUENCY ALLOCATIONS FOR THE PASSIVE SERVICES AT THE 1992 WORLD ADMINISTRATIVE RADIO CONFERENCE

Committee on Radio Frequencies
Board on Physics and Astronomy
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES
Washington, D.C. · 1991

1994 reprinted

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

The Committee on Radio Frequencies acknowledges the assistance of the National Science Foundation and the National Aeronautics and Space Administration, whose continuing support of the committee has made this report possible.

Available from the

Committee on Radio Frequencies
National Research Council
HA-562
2101 Constitution Avenue, NW
Washington, D.C. 20418

Printed in the United States of America

COMMITTEE ON RADIO FREQUENCIES

R. MARCUS PRICE, University of New Mexico, *Chair*
WILLEM BAAN, National Astronomy and Ionosphere Center
WILLIAM COCHRANE, Illinois Natural History Survey
PATRICK C. CRANE, National Radio Astronomy Observatory
A.J. GASIEWSKI, Georgia Institute of Technology
JOHN L. GREEN, National Oceanic and Atmospheric Administration (retired)
TIMOTHY HANKINS, New Mexico Institute of Mining and Technology
THOMAS G. PHILLIPS, California Institute of Technology
JACK B. SNIDER, National Oceanic and Atmospheric Administration
JILL TARTER, National Aeronautics and Space Administration–Ames Research Center
A. RICHARD THOMPSON, National Radio Astronomy Observatory
ROBERT WELLER, Woods Hole Oceanographic Institute

Robert L. Riemer, Senior Program Officer

BOARD ON PHYSICS AND ASTRONOMY

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND APPLICATIONS

CONTENTS

I. INTRODUCTION

The scientific needs of radio astronomers and other users of the passive services for the allocation of frequencies were first stated at the World Administrative Radio Conference held in 1959 (WARC-59). At that time, the general pattern of a frequency-allocation scheme was

1. that the science of radio astronomy should be recognized as a service in the Radio Regulations of the International Telecommunication Union (ITU);

2. that a series of bands of frequencies should be set aside internationally for radio astronomy—these should lie at approximately every octave above 30 MHz and should have bandwidths of about 1 percent of the center frequency; and,

3. that special international protection should be afforded to the hydrogen line (1400-1427 MHz), the hydroxyl (OH) lines (1645-1675 MHz), and to the predicted deuterium line (322-329 MHz).

At the end of WARC-59, considerable action had been taken to meet these needs, and at subsequent conferences (with more limited tasks), the growing extent of the scientific needs has been stated and further steps taken to meet them.

The discovery of radio sources and the bulk of current knowledge about their nature and distribution, and of the processes responsible for the radio emission from them, have come through observations of the continuum radiation (continuous spectra) made at a limited number of frequencies at meter to centimeter wavelengths. Observations of intensity need to be made at a number of frequencies to determine the characteristic spectra of sources; but because the distribution of continuum radiation with frequency is relatively smooth, observations of this kind do not need to be made at specific or closely adjacent frequencies. Bands spaced at intervals of about an octave of the radio-frequency spectrum are normally satisfactory. However, some sources have spectral features requiring observation at closer spacings.

The bands made available to the Radio Astronomy Service, in accordance with the Final Acts of the World Administrative Radio Conference, Geneva, 1979, represent an improvement over the international allocations made to the Service in 1959, 1963, and 1971 and are a partial fulfillment of the requirements of the Service. However, many of the currently allocated bands have insufficient bandwidths; they are, in most cases, shared with active services; many apply to limited areas of the world; and there are large intervals between some of the allocated bands.

As the 1992 WARC approaches, the Committee on Radio Frequencies (CORF) restates in this document the views and needs of radio astronomers and remote sensing scientists for the protection of their research. There is a continuing need for review and updating of the allocations of frequencies for the passive services. The committee notes that with the discovery of new astronomical objects and the development of better equipment and techniques, passive radio scientists regularly use frequencies from the lowest allocated radio astronomy band at 13360-13410 kHz to bands above 500 GHz. The use of passive ground- and satellite-based instruments for meteorological and astronomical observation has further increased the need for more spectrum.

The needs for continuum observations when first stated in 1959 were based largely on the desire to measure the spectra of radio sources over a wide range of frequencies. Since that time, two developments have reinforced this need for continuum bands.

First, pulsars, which are rapidly rotating, highly magnetized neutron stars, have been discovered to be among the most exotic objects in the universe. The physics of pulsars involves the study of matter and radiation under the influence of extreme magnetic, electric, and gravitational fields. Pulsars now provide the most accurate timekeeping, surpassing the world's ensemble of atomic clocks for long-term time stability. They provide the best experimental tests of predictions of the theory of general relativity, the detection of gravitational radiation, and diagnostics of the interstellar medium's density and magnetic field. For these studies continuum bands, particularly those at frequencies below 3 GHz, are most valuable.

Second, the technique of very-long-baseline interferometry (VLBI) now allows radio astronomers and earth scientists to link radio telescopes many thousands of kilometers apart by recording on fast-running, high-density magnetic tape (using very stable oscillators as a reference) and to process the tapes to produce an interferometer system with several very long baselines. The technique of VLBI has proved invaluable in studying the structure of very distant radio sources and in monitoring crustal motions and rotational irregularities of the earth. For this technique to be fully exploited, telescopes in several different countries must observe together on exactly the same frequency. This is made much easier if the same passive frequency bands are protected in all of the regions of the world.

Since 1959 a large number of spectral lines from a wide variety of atoms and molecules in space have been discovered. The frequency range of radio astronomy now extends to at least 500 GHz. In particular the CO molecule, with frequencies at 115, 230, and 345 GHz and isotopes with frequencies at 110, 220, and 330 GHz, is critical to many aspects of astronomy. The opportunity to learn about the gas out of which stars are formed in our own and in distant galaxies depends considerably on access to all of these frequencies. The ground-state fine-structure line of atomic carbon at 492 GHz has been discovered and provides a truly unique opportunity for radio astronomy. However, the protection of spectral-line frequencies is a difficult task. In some simple cases, what is needed is clear; the value of H, OH, and CO line studies has grown, particularly as more sensitive instruments look farther out to objects with increasingly greater red shifts. This, in turn, has made it urgent to look for ways to extend the hydrogen- and hydroxyl-line protection below 1400 MHz, and similarly to extend the protected bands for the lines of OH and CO molecules. For many of the new molecular species, it is difficult to be precise as to their relative scientific importance. Thus continued review of the science, combined with protection of radio astronomy observations by footnote references to the Table of Frequency Allocation in the ITU Radio Regulations, is needed.

There are special difficulties for some spectral lines (the OH lines, for example), where radio emissions from airborne and spaceborne transmitters exist too close to the line frequencies. This difficulty is one that, in recent years, has grown greatly in importance, particularly with the introduction of higher-powered space transmitters and the use of spread spectrum modulation techniques. Because the radio astronomy and remote-sensing sensitivities are so great, and terrain shielding cannot be employed, it is most difficult to avoid interference from the sidebands of some spaceborne transmitters, even though their central transmitting frequencies may lie outside the radio astronomy bands.

As long ago as 1960, the vulnerability of radio astronomy to interference was being documented by the International Radio Consultative Committee (CCIR) of the ITU. Estimates of harmful thresholds for radio astronomy bands were published in CCIR Report 224-6. Thus it is now important to implement ways to protect radio-astronomy and other services from adjacent-band interference from air- and space-to-ground transmissions.

As it has in the past, CORF proposes that the bands allocated to the Radio Astronomy Service be afforded protection to the levels given in CCIR Report 224-6. Within these bands, the flux spectral density produced by services in other bands should not exceed these levels. The Radio Astronomy Service, in return, can claim no special privileges with respect to flux spectral density outside its bands except by mutual agreement with other services or by national arrangements.

The concept of a Lunar Quiet Zone has been studied and advanced as a valuable international resource for radio astronomers and for other scientists who are passive observers of the universe. The study of such a quiet zone has been undertaken within the CCIR and has resulted in CCIR Recommendation 479-3. Radio Regulations (RR29) numbers 2632 to 2635 define the shielded zone of the moon and prohibit harmful interference to radio astronomy except in Space Research and Earth Exploration Satellite bands. Work should continue on determination of appropriate protection of this zone.

The Radio Astronomy Service and the Earth Exploration Satellite Service (Passive) were considered at the 1979 WARC. Allocations to these services have allowed continuing useful research programs to be pursued. It is important that future radio conferences not change the Radio Regulations in ways that will be deleterious to these services. Although these services have additional needs, CORF is not pressing for new allocations or considerations at the 1992 WARC. However, the committee would welcome any changes in the regulations that required the use of better and more modern technical standards. CORF especially encourages the development of additional regulations to protect services from emissions spilling over from adjacent bands.

II. SCIENTIFIC BACKGROUND

Radio Astronomy

The fact that radio waves can be received on the earth from celestial objects was first discovered by Karl Jansky of the Bell Telephone Laboratories in 1932, as a by-product of studies of noise in radio-communication systems. Since that time, the science of radio astronomy has expanded to the point that many types of astronomical objects have been studied by radio methods, and many important discoveries have been made.

Whereas the light waves studied by optical astronomers come from hot objects such as stars, celestial radio waves come mainly from cooler objects, such as the gas between the stars, or from electrons in ordered motion. Radio astronomers study many of the same celestial objects that optical astronomers do, and, in addition, their work has revealed new classes of objects and quite unexpected forms of activity. Astronomical studies provide a laboratory in which matter can be seen over a wide range of physical conditions, the extremes of which cannot now or in the foreseeable future be reproduced on the earth. Extremes of density, temperature, and pressure and unusual chemical compositions can all be found at various places in the universe and are under close study by astronomers.

Some of the sources of radio waves are believed to be at the farthest limits of the known universe. Because these sources are so far away, the radio waves have been traveling for many billions of years, thereby providing information about the condition of the universe a very long time ago. Closer to home, there are large sections of our Milky Way Galaxy that cannot be seen by optical astronomers because light waves are stopped by clouds of interstellar dust; radio waves can penetrate these dust clouds, enabling us to study the whole of our galaxy and other nearby galaxies.

The spectrum of the celestial radio waves reaching the earth contains a broad continuum that covers the whole range of frequencies that can penetrate the earth's atmosphere, together with a large number of atomic and molecular spectral lines, each of which is confined to a narrow frequency range.

The radio continuum arises from two principal mechanisms: (1) thermal emission, the intensity of which is proportional to the temperature, produced in an ionized gas of unbound electrons and protons; and (2) nonthermal emission, mostly produced by the synchrotron process, in which very-high-speed electrons spiral around magnetic-field lines. This mechanism is found in the disks of normal galaxies, in the remnants of supernova explosions, and in unusual types of galaxies known as radio galaxies and quasars.

Spectral line radiation is emitted when an atom or molecule gains or loses a discrete amount of energy. This radiation has a specific frequency and wavelength and thus results in a line in the radio spectrum. Each type of atom and molecule has its own unique set of lines. Widely observed spectral lines occur at a frequency near 1420 MHz, arising from neutral (nonionized) hydrogen atoms in the interstellar gas, and at frequencies of 115 and 230 GHz, arising from carbon monoxide molecules. Other spectral lines have been detected from several atomic species and from a large number of molecules found in space and in planetary and stellar atmospheres.

In the solar system, the sun has always been an important object for study by radio astronomers. The slowly varying component of solar radio emission has been found to provide one of the best indicators of the variation of solar activity over the sun's 11-year cycle. In addition, the intense and rapid bursts of solar radio emission are providing greater understanding of what happens on the sun during active periods and the way the sun influences events in the earth's atmosphere, near-earth space, and other portions of the solar system.

The planet Jupiter also produces frequent bursts of radio waves, and it was the study of these by radio astronomers that first showed the coupling between Jupiter's magnetosphere and the satellite Io. This has been confirmed and extended by measurements in the vicinity of Jupiter from the Pioneer and Voyager spacecrafts.

Radio astronomy has provided new information about the early and late stages of the lives of stars, stages that are important in the evolutionary process but that are not well understood. Strong and localized sources of radiation in spectral lines of the hydroxyl and water molecules are found in the shells of objects that appear to be in the process of becoming stars. Some compact sources of thermal continuum radiation, which are embedded in dense clouds of dust, also seem to be protostellar objects. Recently, giant breeding grounds of massive new stars, and dark clouds where stars similar to the sun are born, have been detected. Millimeter and submillimeter radio telescopes and interferometers are expected to lead astronomers to a new era of understanding of the star formation process.

At the other end of the stellar life cycle, radio astronomers study supernova remnants, the material blown out from massive stars in giant explosions at the end of their lives as stars. Radio astronomers have also discovered numerous very dense and compact neutron stars, which are the remnants of supernova explosions. A rapidly rotating neutron star often is observed as a pulsar, a periodic radio source, which emits a narrow beam of coherent radiation as the neutron star rotates. The period of some pulsars is of the order of a millisecond, making these objects the most stable clocks known.

Spectral lines have now been detected from about 80 different molecules in interstellar space. Many of these are organic molecules, and some are quite complex. These discoveries have raised interesting questions about how complex molecules have been built up and how further development might lead to the precursors of life, as a possibly widespread phenomenon in our galaxy and the wider universe. Astronomers, who study astrochemistry, attempt to trace out the development of a chain of chemical compounds by searching for the appropriate spectral lines. To study the physical conditions inside a molecular cloud, or in different portions of the cloud, it is necessary to compare the relative strengths of lines from different molecules, or of different transitions (lines) from the same molecule. In some cases, a set of lines of a particular type of molecule, involving different isotopes of one or more of the constituent atoms (hydrogen, carbon, nitrogen, or oxygen), can be studied; these studies can give valuable information on the relative densities of the various isotopes in the interstellar medium, and thus indirectly on the general evolution of the chemical elements.

Studies of some spectral lines are more important than others because the atoms or molecules concerned occur in greater numbers, the transitions are more easily excited, or they are particularly good for indicating the conditions inside a cloud or the location of the spiral arms in a galaxy. However, to understand the chemical and physical conditions properly, it is necessary to intercompare a large number of lines.

Studies of galaxies depend heavily on observations of spectral lines at radio wavelengths. These observations provide information on the kinematics of the gas in the galaxies and on the abundance of the elements making up that gas. The hydrogen line has been used to learn about the gravitational potential of the galaxies, leading to the realization that a substantial fraction of the masses of galaxies is made up of material that is not visible. This is called the "missing mass" problem and is vital information in deciding whether the universe will expand forever or will eventually collapse on itself. Further, the hydrogen spectra of galaxies is used for determining their distances and therefore helping to establish the large-scale structure of the universe.

Many distant galaxies are unusually strong continuum emitters of radio waves but are relatively faint when viewed with an optical telescope. These "radio galaxies" are the subject of many investigations attempting to discover the source of their radio energy and the circumstances of the explosive events that seem to have occurred in many of them.

The most powerful radio sources known are quasars, which are distant, compact objects that emit radio energy at a prodigious rate. A quasar is believed to be the nucleus of a galaxy that is usually too distant for anything but the central core to be seen. The study of quasars involves fundamental physics, in the continuing attempt to understand their sources of energy. The nuclei of some other classes of galaxies show great activity and unusual energy production. Even the nucleus of our own galaxy is a small-scale version of an active nucleus and can best be studied by radio methods.

Remote Sensing of the Earth

Observations of the earth's atmosphere, land areas, and oceans in the radio part of the electromagnetic spectrum have become increasingly important in understanding the earth as a system. Currently operational satellite instruments, including the Microwave Sounding Unit (MSU) and instruments on the U.S. Air Force's passive microwave weather satellites (SSM/I and SSM/T) provide key meteorological data sets. Future remote-sensing satellite missions such as NASA's Earth Observing System (EOS) and the Tropical Rainfall Measurement Mission (TRMM) are currently under planning. The missions are expected to improve measurements of atmospheric temperature, water vapor and precipitation, soil moisture, concentrations of ozone and other trace gases, and sea surface temperature and salinity. These multiyear, multibillion-dollar missions are international in scope, reflecting the interests of many countries in obtaining accurate meteorological, hydrological, and oceanographic data, and measurements of land surface features and trace gases in the atmosphere.

The outcome of such remote sensing missions will be improvements in weather forecasting; severe storm monitoring; water resources, land, and biota management; and improved global climate and atmospheric chemistry models. The long-term economic impact of the information from remote sensing satellites promises to be substantial, in both the production of food and other agricultural products and the operation of businesses and industries that are dependent on both local weather and long-term climate stability. A substantial number of lives can be saved through advanced warning of dangerously inclement weather. The remotely sensed information will also be used to provide scientifically based guidelines for environmental policy.

Passive Sensors

A major component of earth remote sensing systems consists of spaceborne passive microwave radiometers. These sensors are similar in their basic design and sensitivity to radioastronomy receivers and are essential to the overall success of satellite-based earth remote sensing missions, due to their ability to probe through optically thick clouds. This unique feature of passive microwave sensing complements the capabilities of infrared and optical sensors.

As in radioastronomy, bands near certain atmospheric spectral lines and transmission windows are required for passive earth exploration satellites. Several bands, listed in Tables 1 and 2, have been identified and investigated for their particular capabilities. Atmospheric temperature profiles can be measured using channels near O_2 absorption lines at 50-70 GHz (within the 5-mm absorption band) and at 118 GHz. Water vapor profiles can be measured using channels near H_2O absorption lines at 22.235 and 183.310 GHz, and potentially at 325 GHz. Precipitation exhibits no narrow spectral features and thus requires a widely spaced set of channels for observation. Useful channels are near 6, 10, 18, 37, 90, 157, and (potentially) 220 and 340 GHz.[1] Soil moisture measurement requires a low-frequency microwave channel near 1 to 3 GHz. Sea surface temperature and wind speed measurements require channels at slightly higher frequencies, near 6, 10, and 18 GHz. Concentrations of atmospheric trace gases (e.g., ozone) can be measured by observing atmospheric radio emissions near molecular resonances.

The required sensitivities for retrieval of geophysical parameters are listed in Table 1, in terms of the required accuracy of the brightness temperature values, which range from 0.1 to 1.0 K. In order to obtain these sensitivities, wide bandwidths (from 60 MHz to 6 GHz) are required. The particular bandwidth requirement depends on the use of the channel, the receiver sensitivity, and the observation time; minimum acceptable bandwidths are given in Table 1. The listed bands are consistent with CCIR Recommendation 515, "Frequency Bands and Performance Requirements for Satellite Passive Sensing," although wider bandwidths are suggested for some frequencies.

In order to obtain the sensitivity required for earth remote sensing, interference from radio sources must be kept below the thresholds described in CCIR Report 694. The current allocations for passive earth exploration satellites were made during the 1979 WARC.

Active Sensors

Another critical component of current and planned earth remote sensing systems consists of active spaceborne sensors, such as synthetic aperture radars (SARs), radar altimeters, and precipitation radars. Uses of active sensors include measurement of soil moisture, snow, ice, rain, clouds, atmospheric pressure, and ocean wave parameters, and mapping of geologic and geodetic features and vegetation.

Suggested channels for active earth remote sensing are 100-MHz-wide frequency bands near 1, 3, 5, 10, 14, 17, 35, and 76 GHz. Wider bandwidths (up to 600 MHz) are required for altimeter measurements with vertical resolution less than 50 cm. These bands are consistent with CCIR Recommendation 577-1, "Preferred Frequency Bands for Active Sensing Measurements." The current allocations for active earth remote sensing were made during the 1979 WARC.

---

[1]The High Resolution Multifrequency Microwave Radiometer, part of NASA's planned Earth Observing System (EOS), includes the Advanced Microwave Sounding Unit, which will provide atmospheric soundings of temperature and water vapor using channels in the oxygen resonance band (50-60 GHz) and the water vapor line at 183 GHz; the Advanced Mechanically Scanned Radar, a microwave imager operating at 6, 10, 18, 21, 37, and 90 GHz; and the Electronically Scanned Thinned Array Radiometer, an imaging radiometer that operates at 1.43 GHz.

TABLE 1 Passive Earth Exploration Channels (after CCIR Recommendation 515)

Frequency (GHz)	Suggested Bandwidth (MHz)	Required Accuracy (K)	Measurements
Near 1.4	100	0.1	soil moisture
Near 2.7	60	0.1	salinity, soil moisture
Near 5	200	0.3	estuarine temperature
Near 6	400	0.3	ocean temperature, rain
Near 10	100	1.0	rain, snow, ice, sea state
Near 15	200	0.2	water vapor, rain
Near 18	200	0.2	rain, ocean ice, water vapor, sea state
Near 21	200	0.2	water vapor, rain
22.235	300	0.4	water vapor, rain
Near 24	400*	0.2	water vapor, rain
Near 31	500	0.2	ocean ice, oil spills, rain, clouds
Near 37	1000	0.7	rain, snow, ocean ice, water vapor, sea state
50-61.5	250†	0.1	temperature
64-66	100†	0.1	temperature
Near 90	6000*	0.7	clouds, oil spills, ice, snow
100.49	2000	0.2	nitrous oxide
110.80	2000*	0.2	ozone
115.27	2000	0.2	carbon monoxide
118.75	6000¶	0.1	temperature
125.61	2000	0.2	nitrous oxide
150.74	2000	0.2	nitrous oxide
Near 157	2000	0.7	rain, cloud water, water vapor
164.38	2000	0.2	chlorine oxide

Continued

TABLE 1 (*Continued*)

Frequency (GHz)	Suggested Bandwidth (MHz)	Required Accuracy (K)	Measurements
Near 166	4000*	0.7	rain, cloud water, water vapor
167.20	2000	0.2	chlorine oxide
175.86	2000	0.2	nitrous oxide
183.31	18,000¶	0.1	water vapor, clouds
184.75	2000	0.2	ozone
200.98	2000	0.2	nitrous oxide
Near 220	6000*	0.7	rain, clouds
226.09	2000*	0.2	nitrous oxide
230.54	2000	0.2	carbon monoxide
235.71	2000	0.2	ozone
237.15	2000	0.2	ozone
251.21	2000*	0.2	nitrous oxide
276.33	2000	0.2	nitrous oxide
301.44	2000	0.2	nitrous oxide
325.10	18,000¶	0.1	water vapor, clouds
Near 340	6000	0.5	water vapor, clouds
345.80	2000	0.2	carbon monoxide
364.32	2000	0.2	ozone
380.20	2000	0.2	water vapor
Near 420	6000	0.5	water vapor, clouds
424.76	6000	0.1	temperature, clouds

NOTE: Center frequencies and bandwidths have been modified for some channels.

*The current frequency allocation is acceptable.
†Several O_2 channels lie within this range.
¶Several double sideband channels are centered around the absorption line peak within this range.

TABLE 2 Microwave Frequencies Utilized by the National Oceanic and Atmospheric Administration

Channel Number	Center Frequency	Bandwidth (MHz)	Stability (MHz)	NEDT (K)
1	23.8 GHz	270	10	0.3
2	31.4 GHz	180	10	0.3
3	50.3 GHz	180	10	0.4
4	52.8 GHz	400	5	0.25
5	53.596 GHz	170	5	0.26
6	54.4 GHz	400	5	0.25
7	54.94 GHz	400	5	0.25
8	55.5 GHz	330	10	0.25
9	57.290344 GHz=f_{LO}	330	0.5	0.25
10	f_{LO} ±217 MHz	78	0.5	0.4
11	f_{LO} ±322.2 ±48 MHz	36	0.5	0.4
12	f_{LO} ±322.2 ±22 MHz	16	0.5	0.6
13	f_{LO} ±322.2 ±10 MHz	8	0.5	0.8
14	f_{LO} ±322.2 ±4.5 MHz	4	0.5	1.2
15	89.0 MHz	6000	50	0.5
16	60.79267 ±0.3539 GHz	3	0.03	1.5
17	60.79267 ±0.3558 GHz	0.8	0.03	2.8
18	60.79267 ±0.3569 GHz	0.5	0.03	3.5
19	60.79267 ±0.3579 GHz	1.0	0.03	2.5
20	60.79267 ±0.3589 GHz	0.5	0.03	3.5
21	60.79267 ±0.3600 GHz	0.8	0.03	2.8
22	89.0 GHz	6000	50	1.0
23	157.0 GHz	4000	50	1.0
24	183.31 ±1.0 GHz	1000	50	1.0
25	183.31 ±3.0 GHz	2000	50	1.0

Searching for Evidence of Extraterrestrial Technologies

In 1959, Cocconi and Morrison published a paper suggesting that the technology of radio astronomy had progressed to the point that interstellar communication between ourselves and a very distant civilization might be possible. They suggested the 1420-MHz line of neutral hydrogen as an obvious universal communication channel. Independently, Frank Drake made the first radio search for extraterrestrial intelligence (SETI) using the Tatel telescope of the National Radio Astronomy Observatory equipped with a single-channel, narrowband spectrometer and a receiver tuned to 1420 MHz. Project OZMA, as this search was called, was conducted in the spring of 1960 and examined two nearby solar-type stars for a few hundred hours. It was the first of nearly 60 searches that have been made over the past three decades, most of them at radio frequencies.

Footnote 722, added to the Radio Regulations during the 1979 WARC, recognizes the interest of the radio science community in this passive search technique. Since 1960, improvements in receiver technology and digital signal processing equipment, intended primarily for use in radio astronomy, have enabled far more sensitive and sophisticated searches for extraterrestrial technologies to be conducted. Making use of receiver instrumentation developed for radio astronomy, these searches have remained clustered about the frequencies of natural atomic and molecular emission lines and within the protected radio astronomy bands. Plausible arguments can be made for searching at these "magic frequencies," but most of the microwave window has remained unexplored. We can of course only speculate on the likelihood of civilizations with matching technology.

Starting in 1992 NASA will inaugurate a systematic search for signals throughout the 1- to 10-GHz frequency range that represents the clearest microwave window through the terrestrial atmosphere. This search will be based on state-of-the-art signal processing equipment and wideband, low-noise receivers and feeds developed specifically for SETI. The search will be conducted with two complementary strategies, a targeted search of the nearest 1000 solar-type stars using the world's largest radio telescopes and an all-sky survey using the 34-meter antennas of NASA's Deep Space Network. Although this search will be billions of times more comprehensive than even the most ambitious search currently under way—the META projects of the Planetary Society using dedicated telescopes in Massachusetts and Argentina—it is still a limited search and may not succeed.

Because of the technical challenges alone, SETI is an important scientific endeavor. SETI experiments require advanced methods of signal processing as an attempt is made to recognize and interpret weak signals of unknown intensity, frequency, and temporal characteristics amidst a background din of terrestrial and cosmic noise. As with more traditional astronomical studies of weak cosmic radio emission, terrestrial interference poses the greatest challenge to this microwave search. If all the frequencies are to be observed for all the targets and directions on the sky, techniques will have to be found to mitigate against, or work around, the ground-based and satellite transmissions from all the active services making use of the 1- to 10-GHz frequency range. If the search is unsuccessful, future searches may need to be conducted from the Lunar Quiet Zone on the lunar far side (see Chapter VI). As with traditional radio astronomy and remote sensing of the earth, SETI would benefit greatly from the adoption of modern technical standards and the reduction of out-of-band emissions from active services.

Technological Contributions

The history of radio astronomy and earth remote sensing has shown a remarkable rate of important and unexpected discoveries. In the short period of the last four decades, radio scientists have made fundamental new discoveries in physics and have brought us closer to understanding both the nature of the universe and our immediate environment. The rapid rate of important discoveries in radio astronomy and atmospheric science will surely continue. Such progress is assured in part by protecting radio-frequency bands for the passive services.

Radio astronomy and remote sensing have contributed to the development of practical devices and techniques. Some of these are listed below:

- The development of very-low-noise receivers with system temperatures as low as 10 K and frequencies extending from a few MHz to 1000 GHz. These have wide applications in radio technology.
- The study of the thermography of the body by use of millimeter radio techniques (~45 GHz).
- The detection of breast cancer at centimeter wavelengths (~10 GHz) with modern radiometers.
- Computerized x-ray tomography, which employs methods originally developed for mapping radio sources.
- The detection of forest fires by their microwave radiation.
- The identification of potential earthquake zones by very-long-baseline interferometric (VLBI) measurements of fault motion.
- The determination of many geophysical parameters such as continental drift, polar wandering, latitude measurements, and variations in the earth's rotation, with the use of connected-element and VLBI techniques.
- Major contributions to navigation—including that of spacecraft—and timekeeping resulting from pulsar observations, VLBI, and the verification of Einstein's general theory of relativity.
- Measuring the temperature of the earth's atmosphere, surface properties, and the distribution of water vapor, cloud water, precipitation, and impurities such as carbon monoxide by passive remote-sensing techniques.
- Monitoring of trace gases, such as ozone, important to atmospheric chemistry.

Radio astronomy is an active and vigorous science, in which the universe and its component parts are studied and new discoveries made at a rapid rate. The foregoing account is a selection of only a few examples. To continue this rapid advance, it is necessary to operate many radio observatories with different instruments and locations, including space, and to be able to observe at many different frequencies. Countries around the world that have devoted large sums of money for the development of radio astronomy include Argentina, Australia, Brazil, Canada, China, Germany, France, India, Italy, Japan, The Netherlands, the United Kingdom, the United States, and the U.S.S.R. It is anticipated that this support will continue and that other countries will start major radio-astronomical projects.

III. GENERAL CONSIDERATIONS ON FURTHER PROTECTION

In the remarks below, specific frequencies actually refer to frequency bands.

1. The gap between the 74-MHz and the 408-MHz continuum allocations is too broad. A frequency band in the range 130-250 MHz with a 1- to 2-percent bandwidth is urgently needed. Footnote protection, at least, should be provided. The band 150.05 to 153 MHz is protected in Region 1. Such a frequency allocation would be especially useful for pulsar research and for VLBI.

2. The 1979 WARC provided an allocation for the passive services in the 322-328.6 MHz band. This band serves both line and continuum observations, since it includes the hyperfine transition from the cosmologically significant deuterium atom. This has become an important band for radio astronomers all over the world, with its use for VLBI and on the Very Large Array (VLA). However, this band is not allocated to the passive services in the United States.

3. The 608-614 MHz band has different detailed allocations for each region. A single worldwide band is desired to allow pursuit of international VLBI observations. Coordination with television transmissions on adjacent channels would be desirable.

4. The primary, exclusive allocation in the 1400-1427-MHz band should be preserved for studies of neutral atomic hydrogen and for passive earth remote sensing of soil moisture. Additional protection in the 1330-1400-MHz band is also required for studies of distant galaxies.

5. Important spectral lines should have their allocation status upgraded to "Primary" in the allocation table. This is particularly pertinent in the case of the OH lines at 1612 MHz, and 1720 MHz. The bandwidths should be at least wide enough to cover the expected Doppler-shift range found in our galaxy.

6. The 2695-MHz (11-centimeter) band is important to radio astronomy. Its bandwidth is small considering its relative importance, and efforts should be made to increase this bandwidth. This frequency band is also useful for passive remote sensing of the earth's surface parameters.

7. The allocation status for the H_2CO line at 4830 MHz should be upgraded to "Primary" in the allocation table. The bandwidths should be at least wide enough to cover the expected Doppler-shift range found in our galaxy.

8. The 4990-MHz (6-centimeter) band has become one of the most important for continuum radio astronomy. The frequency is used in almost all observatories as a primary frequency for continuum and VLBI measurements. Improved protection in the 4800-4990-MHz band is desirable.

9. The water vapor and ammonia lines at 22.2 GHz and around 23 GHz are important diagnostic lines of the interstellar medium of our galaxy and other galaxies. The protection of these lines needs to be improved.

10. The continuum bands above 80 GHz now allocated to the Radio Astronomy Service and the Earth Exploration Satellite Service are particularly useful because they have large enough bandwidths to take full advantage of modern receiver technology, and they are situated in regions of the spectrum where atmospheric windows exist.

11. In general, a 1- to 2-percent bandwidth is the minimum practical allocation; a 5-percent bandwidth would be desirable for the continuum bands. This is strongly reinforced by the new and rapidly increasing requirements for bandwidth allocation at all frequencies, for complex molecular line studies in the galaxy and for red-shifted lines of distant galaxies. This requirement can be met by the use of the same fractional bandwidth allocations for spectral lines as for continuum astronomy as long as the allocated bands occur reasonably frequently throughout the full spectrum.

12. In the last 30 years, radio astronomy studies have demonstrated the presence of ever-more-complex molecules in interstellar space. These discoveries have been one of the most fascinating and puzzling developments in the field. The complexity of the largest molecules already exceeds that of simple amino acids. It is anticipated that, in the future, still more complex molecules, and possibly amino acids, will be found. Identification of complex molecules can be made only by detection of a number of radio lines.

13. Passive services have considered, in a preliminary fashion, those spectral lines at frequencies above 275 GHz that may merit the granting of protection at some future WARC. Since the 1992 WARC will not address this frequency range, it is not discussed in this document. The most important spectral lines for radio astronomy are listed in CCIR Recommendation 314-7. This list is developed and updated regularly by a working group within the International Astronomical Union.

14. Strong efforts must be made to protect radio astronomy bands from adjacent band interference from air- or space-to-ground transmissions. Table 3 shows the potential interference situation from air- or space-to-ground transmission adjacent to the primary radio-astronomy bands. Passive services are particularly sensitive to spurious, out-of-band and harmonic emissions from other services. A major effort to modernize and upgrade engineering standards for active services should be made, especially with regard to out-of-band emissions. Modernization of these standards would be useful to other services as well as to radio astronomy. This is particularly the case with airborne and satellite transmitters and devices that do not require licensing.

TABLE 3 Services in Adjacent Bands That Could Cause Harmful Interference to the Radio Astronomy Service

Band Allocated to Radio Astronomy on a Worldwide Primary Basis	Adjacent Band	Adjacent-Band Services
13.36-13.41 MHz	13.26-13.36 MHz	AERONAUTICAL MOBILE (R)
322-328.6 MHz	273-322 MHz 328.6-335.4 MHz	MOBILE, including satellite AERONAUTICAL RADIONAVIGATION
1400-1427 MHz	1350-1400 MHz 1429-1525 MHz	RADIOLOCATION MOBILE (except Region 1) Broadcasting satellite*
1660-1670 MHz	1656.5-1660.5 MHz 1670-1690 MHz	LAND MOBILE-SATELLITE (earth-to-space)† METEOROLOGICAL AIDS METEOROLOGICAL-SATELLITE (space-to-earth)
2690-2700 MHz	2655-2690 MHz 2700-2900 MHz	BROADCASTING-SATELLITE (space-to-earth) FIXED-SATELLITE (Region 2) AERONAUTICAL RADIONAVIGATION Radiolocation
4990-5000 MHz	4800-4990 MHz 5000-5250 MHz	MOBILE AERONAUTICAL RADIONAVIGATION
10.6-10.7 GHz	10.55-10.6 GHz 10.7-11.7 GHz	Radiolocation FIXED-SATELLITE (space-to-earth)
15.35-15.4 GHz	14.8-15.35 GHz 15.4-15.7 GHz	MOBILE Space research AERONAUTICAL RADIONAVIGATION
22.21-22.5 GHz	22.5-22.55 GHz	MOBILE BROADCASTING-SATELLITE (Regions 2 & 3)
23.6-24 GHz	23.55-23.6 GHz 24-24.05 GHz	MOBILE AMATEUR AMATEUR-SATELLITE

Continued

TABLE 3 *(Continued)*

Band Allocated to Radio Astronomy on Worldwide Primary Basis	Adjacent Band	Adjacent-Band Services
31.3-31.8 GHz	31-31.3 GHz	MOBILE Standard signals-Satellite (space-to-earth) Space research
	31.8-32 GHz	RADIONAVIGATION Space research
42.5-43.5 GHz	40.5-42.5 GHz	BROADCASTING-SATELLITE Mobile
	43.5-47 GHz	MOBILE MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE
86-92 GHz	84-86 GHz	MOBILE BROADCASTING-SATELLITE
	92-95 GHz	MOBILE RADIOLOCATION
105-116 GHz	102-105 GHz	FIXED-SATELLITE (space-to-earth) MOBILE
	116-126 GHz	INTER-SATELLITE (space-to-earth) MOBILE
164-168 GHz	151-164 GHz	FIXED-SATELLITE (space-to-earth) MOBILE
	168-170 GHz	MOBILE
182-185 GHz	176.5-182 GHz	INTER-SATELLITE MOBILE
	185-190 GHz	INTER-SATELLITE, MOBILE
217-231 GHz	202-217 GHz	MOBILE
	231-235 GHz	FIXED-SATELLITE (space-to-earth) MOBILE Radiolocation
265-275 GHz	252-265 GHz	MOBILE MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE

NOTE: Fixed and mobile services, except aeronautical mobile services, are not included.

*Under study (see Resolution No. 505 of WARC-79).
†See also footnote 730A (MOB-87) of the Radio Regulations.